HUMAN-AI COLLABORATION IN SCIENCE EDUCATION: CHALLENGES AND STEPS FORWARD

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AI technologies are reshaping our world and prompting education scholars to rethink both the aims and methods of schooling to prepare learners for the future (Holmes et al., 2019). Meanwhile, interest in integrating AI into science education has grown, with much discussion focusing on the impact of AI on student engagement and learning performance. Among those interests and debates, questions arise about AI's ability to provide instructional, learning, and evaluative tools, as well as the practices and challenges of teacher-AI collaboration in education.

A consistent finding across recent studies is that AI can augment, not replace, teacher expertise. When AI is thoughtfully designed and supported, AI-enabled environments support multimodal, collaborative learning that combines teacher guidance with learner autonomy. Across the literature, several roles for AI for different stages of science teaching emerged, including co-planning and co-teaching (e.g., Nazaretsky et al., 2022; Williyan et al., 2024; Yorulmaz et al., 2025), co-creating content and resources, promoting project-based learning and game-based learning pedagogies (Lee et al., 2021), and co-assessing of the learning process (Nazaretsky et al., 2022), to name a few. Along with all those roles, AI is capable of providing more targeted feedback and boosting students' engagement (Erduran, 2023).

While these findings indicate that AI can scaffold inquiry, surface alternative explanations, and diversify instructional strategies while preserving teacher decision-making authority, challenges exist in human-AI collaboration in education. One thing worth mentioning is that the combination of human intelligence and artificial intelligence is not always more effective than doing it by human or AI alone, since human-AI collaboration operates along a dynamic spectrum, requiring different balances of human control and AI automation depending on the nature of the learning task, learning environment, and the individuals' competency. However, currently, we still lack empirical evidence of best practices regarding the patterns and effectiveness of human-AI collaboration in education, especially in science education. A recent meta-analysis on the effectiveness of human-AI collaboration (in general) found that human–AI combinations performed differently based on types of task and the ability of both human and AI (Vaccaro et al., 2024). Evidence from HAIC in education suggests that AI systems frequently underperform relative to humans in several key areas: reading students' emotions during learning, interpreting social interactions, and grasping domain-specific knowledge that is not adequately captured by training data (Cohn et al., 2025). Consequently, hybrid approaches that combine human expertise with AI are needed to address these limitations. We need more empirical studies like this that address these questions and contribute to our understanding of the best human-AI collaboration trajectories and the outcomes that different trajectories lead to.

Looking forward, what concrete steps should researchers, educators, and policymakers take to advance responsible, effective human–AI collaboration in science education? To begin, promote professional development that enables teachers to participate in co-design and iterative refinement of AI-enhanced curricula. This includes promoting trust in AI technology among teachers since it is essential for successfully integrating AI into organiza-

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tions (Glikson & Woolley, 2020), training on interpreting AI outputs, contextualizing AI recommendations within disciplinary goals, and maintaining a critical stance toward AI recommendations. Second, cultivate open, adaptable AI tools co-created with teachers to ensure relevance to diverse classrooms and contexts (Williyan et al., 2024). Third, research and implement robust assessment frameworks that capture not only student achievement, shifts in scientific reasoning, collaboration, and AI literacy, but also dynamic changes in the human-AI collaboration loops. Finally, align AI integration with disciplinary standards and inquiry-based pedagogy, ensuring that AI augments, rather than fragments, the coherence of science learning.

To conclude, human–AI collaboration in science education offers substantial potential to enrich teaching and learning, on the condition that AI functions as a collaborative partner guided by teacher expertise, ethical principles, and a commitment to equity. Realizing this potential requires deliberate, evidence-based design decisions, professional development that centers on teacher agency, and governance frameworks that foster trust and transparency in AI-assisted learning. By sustaining an ongoing partnership among teachers, researchers, and AI developers, we can foster collective intelligence in human-AI collaboration that illuminates scientific reasoning, personalizes instruction, and supports students in developing robust scientific understandings for the twenty-first century.

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